How hearing impairment may impact adult life

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Chapter 5

DETERIORATION OF SPEECH RECOGNITION ABILITY OVER A PERIOD OF FIVE YEARS IN ADULTS AGED 18 TO 70 YEARS: RESULTS OF THE DUTCH ONLINE SPEECH-IN-NOISE TEST

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ABSTRACT

Objectives: The first aim of the present study was to determine the change in speech recognition in noise over a period of five years in participants aged 18 to 70 years at baseline. The second aim was to investigate whether age, gender, educational level, the level of initial speech recognition in noise, and reported chronic conditions were associated with a change in speech recognition in noise.

Design: The baseline and five-year follow-up data of 427 participants with and without hearing impairment participating in the National Longitudinal Study on Hearing (NL-SH study) were analyzed. The ability to recognize speech in noise was measured twice with the online National Hearing Test (NHT), a digit-triplet speech-in-noise test. Speech-Reception-Threshold in noise (SRTn) scores were calculated, corresponding to 50 percent speech intelligibility. Unaided SRTn scores obtained with the same transducer (headphones or loudspeakers) at both test moments were included. Changes in SRTn were calculated as a raw shift (T1–T0) and an adjusted shift for regression towards the mean. Paired t-tests and multivariable linear regression analyses were applied.

Results: The mean increase (i.e., deterioration) in SRTn was 0.38 dB signal-noise-ratio (SNR) over five years ($p<0.001$). Results of the multivariable regression analyses showed that the age group of 50 to 59 years had a significantly larger deterioration in SRTn compared with the age group of 18 to 39 years (raw shift: beta: 0.64 dB SNR; 95% CI: 0.07-1.22; p:0.028, adjusted for initial speech recognition level – adjusted shift: beta: 0.82 dB SNR; 95% CI: 0.27-1.34; p:0.004). Gender, educational level, and the number of chronic conditions were not associated with a change in SRTn over time. No significant differences in increase of SRTn were found between the initial levels of speech recognition (i.e., good, insufficient, or poor) when taking into account the phenomenon regression towards the mean.

Conclusions: Our study results indicate that hearing deterioration of speech recognition in noise over five years can also be detected in adults aged 18 to 70 years. This rather small numeric change might represent a relevant impact on an individual’s ability to understand speech in everyday life.

INTRODUCTION

Hearing loss is regarded as one of the most frequently occurring chronic conditions worldwide (WHO, 2008). Multiple studies have investigated the prevalence and risk factors of hearing loss. Both environmental (e.g., noise exposure, medication, and medical conditions), as well as genetic factors contribute to the development of age-related hearing loss (Van Eyken et al., 2007). A consistent finding across these studies is that pure-tone thresholds worsen with age (e.g., Karlsmose et al., 1999; Engdahl et al., 2005; Agrawal et al., 2009; Cruickshanks et al., 2010; Lin et al., 2011; Mitchell et al., 2011; Kiely et al., 2012). In an extensive longitudinal study by Morrell et al. (1996), pure-tone threshold changes over time were modelled per age decade for the age of 30 years onward. It was shown that the longitudinal change of the average thresholds at 2, 3, and 4 kHz steadily increased comparing the younger with the older age groups over time. The data analysis in a study by Kiely et al. (2012) in older adults supports this finding. Thus, older adults have worse hearing ability than their younger counterparts, and hearing acuity in quiet deteriorates faster in older adults compared with younger adults.

Besides pure-tone audiometry, other measurements to determine a person's hearing ability exist, and are widely used. An example is a speech-in-noise test. Problems with speech understanding in noise are found as the primary and most limiting consequence of hearing impairment (e.g., Plomp & Mimpen, 1979; King & Stephens, 1992; Kramer et al., 1998). With a speech-in-noise test this ability to recognize speech in background noise can be measured. Both words and sentences are used as speech stimuli in existing speech-in-noise-tests (Stephens & Kramer, 2010).

Approximately ten years ago, Smits et al. (2004; 2006) developed the digit-triplet speech-in-noise test in the Netherlands, which has been designated the National Hearing Test (NHT). This test is a functional hearing screening self-test, which was initially developed to be administered by telephone. More recently, an Internet version was launched (Smits et al., 2006). The NHT determines the Speech-Reception-Threshold in noise (SRTn), defined as the Signal-to-Noise Ratio (SNR) in decibel (dB) corresponding to 50% recognition of digit triplets in steady state noise. Several versions of the NHT in different languages have been developed and are currently being implemented worldwide (Watson et al., 2012; Zokoll et al., 2012; Dawes et al., 2014).

The first prospective epidemiological study in which the NHT was incorporated was the Longitudinal Aging Study Amsterdam (LASA). LASA focuses on physical, emotional, cognitive, and social functioning in later life. The main aim of LASA is to investigate the determinants, trajectories, and consequences in these domains of functioning in relation to aging (Huisman et al., 2011). In a study examining the longitudinal change in NHT scores, a mean deterioration in SRTn of 0.18 dB SNR per annum was reported in adults 57 to 93 years of age at baseline (Pronk et al., 2013). Deterioration of SRTn amongst the older age groups was found to be larger than for the younger age groups. For the group aged 57 to 75 years it was 0.14 dB SNR per annum, and for the group aged 75 to 93 years it was 0.26 dB SNR per annum (Pronk et al., 2013). It was suggested that around the age of 75 years, the decline in speech recognition accelerates. However, this effect was not reported in other longitudinal studies using speech-in-noise recognition measures (Divenyi, Stark, & Haupt, 2005; Dubno et al., 2008).

Lower educational achievement has been associated with a higher incidence of pure-tone hearing loss (e.g., Cruickshanks et al., 2003; Cruickshanks et al., 2010), but it is unknown whether this factor influences the change of speech recognition ability over time. An earlier cross-sectional study found an association between hearing ability in noise and the likelihood of higher educational achievements (Stam et al., 2013). Those with poor hearing ability were less educated and it was therefore suggested that this prospective relationship between education and speech recognition needed further investigation.

There is also evidence that specific chronic conditions such as diabetes and cardiovascular disease are associated with age-related hearing loss (Van Eyken et al., 2007). However, the effects of chronic conditions on the course of speech recognition in noise over years have not been thoroughly investigated. In a study by Pronk et al. (2013) none of the studied chronic conditions (e.g., diabetes, hypertension, stroke) were relevant factors in the association between time and the deterioration in SRTn (no confounding effects). However, in this study, it was not investigated whether the change in SRTn over time was different for older adults with or without chronic conditions. Since there is accumulating evidence demonstrating an association between hearing loss and diabetes (Horikawa et al., 2013), more knowledge about the association between chronic conditions and speech recognition deterioration in adults is required. Such knowledge may help to demonstrate the potential relevance of joint screening programmes, for instance.

Evidence about the decline in speech recognition in noise over time is predominantly based on studies in relatively old adult populations. To illustrate, the age ranges in previous studies were 57 to 93 years (Pronk et al., 2013); 51 to 87 years (Dubno et al., 2008); and 60 to 83.7 years (Divenyi et al., 2005). More evidence from various study populations, with different age ranges, and consideration of people's baseline speech recognition level, is needed to further investigate the effects of socioeconomic and health status on the course of adults' speech recognition over years.

Tests of speech recognition in noise may be of additional value to understand functional hearing over a lifetime. It is also an important issue from the patient's perspective as they often want to know whether their decline in hearing is likely to progress. In clinical practice, it may be useful to have more knowledge about the possibilities of identifying subgroups of adults susceptible for a decline in hearing. Such knowledge may help the development of specific rehabilitation or monitoring programs and for prevention of future decline in the hearing of speech.

The current study describes the first follow-up results of the Dutch National Longitudinal Study on Hearing (NL-SH). The aim was twofold. The first objective was to determine the change in speech recognition ability in noise over a period of five years in participants aged 18 to 70 years at baseline. The second objective was to investigate whether age, gender, educational level, initial speech recognition level, and reported chronic conditions were associated with a change in speech recognition in noise. This prospective data will expand knowledge regarding the change in speech recognition ability over a five-year period in adults.

MATERIALS AND METHODS

Data collection

Baseline (hereafter referred to as T0) and five-year follow-up data (T1) from the NL-SH study were used for the present study. The NL-SH is an ongoing prospective cohort study in the Netherlands which commenced in 2006. The NL-SH examines relationships between hearing impairment and several aspects of the lives of adults between 18 and 70 years. The aim of the NL-SH is to create a convenience sample of the Dutch population, including both normal-hearing and hearing-impaired adults, and to compare groups of participants with and without hearing impairment on a range of variables. The NL-SH Web site (**www.hooronderzoek.nl** [in Dutch]) was used to recruit participants, and to collect data (Nachtegaal et al., 2009a; 2009b). Before enrolment in the study, participants had to perform the NHT. This test is available online (**www.hoortest.nl**) as well as on the NL-SH Web site (for more information see *Hearing ability in noise*). Participants who completed the NHT, and subsequently subscribed themselves for the NL-SH study by filling in an online registration form on the NL-SH Web site, received an email with a link to their personal online questionnaire. This link was sent to the participant within one week after subscription. The NL-SH questionnaire contains a set of validated questions about hearing, demographic and socioeconomic status, health and psychosocial health status, participation in work, and use of health care.

Participants who completed the T0 measurement in 2006 or 2007 and were still participating in 2011 or 2012 were invited for T1. A five-year interval was chosen, predominantly because this cutoff point was also used in other longitudinal studies (e.g., Karlsmose et al., 2000; Cruickshanks et al., 2003; Burr et al., 2005), and thus makes us able to compare findings. As the NL-SH study is a Web-based study, the entire data collection was via the Internet. We aimed to perform the T1 measurement exactly five years following each individual’s T0 measurement. Hence, all participants who completed their T0 measurement in November 2006 were invited again in October 2011. We took into account a one-month interval between receiving the invitation and actually responding to it and completing the questionnaire at T1.

Participants who did not respond received regular reminders. If a participant did not respond within one week, they received a reminder via e-mail. After one month, a reminder by post was sent, followed by another e-mail one week later (in case of nonresponse). A final e-mail reminder was sent to those who did not respond after two to three months.

The procedure of data collection was similar in both rounds of measurements (T0 and T1) with a few exceptions. At T0, participants first performed the NHT followed by the questionnaire. For the second measurement (T1), the questionnaire was completed, followed by the NHT. After finishing the questionnaire, participants were directed to the NL-SH Web site where they could perform the NHT again. Participants received an informative factsheet about the NL-SH study as a little gift after their complete participation.

The NL-SH study (including the follow-up round of measurements) was approved by the Medical Ethics Committee of the VU University Medical Center in Amsterdam, The Netherlands.

Hearing ability in noise

The participants' ability to understand speech in noise was tested with the NHT (Smits et al., 2004; 2006) at both T0 and T1. A total of 23 digit triplets (e.g., 6-2-5) were presented against a background of stationary masking noise, according to an adaptive one-up, one-down procedure, using 2-dB steps. After each incorrect response, the subsequent triplet was presented at a level 2-dB higher than before. If the participant provided a correct response, the subsequent triplet was presented 2-dB quieter. The noise level was unchanged throughout the test. Listeners responded by typing the digits on their keyboards or by clicking their computer mouse on the digits displayed on their computer screen. Either headphones or loudspeakers were used according to the participants' preference. Respondents were instructed to perform the NHT in a quiet room. At the start of the test, participants were required to indicate which type of transducer they were using. When headphones were used, the digits were presented to both ears (diotically).

The SRTn was calculated by using the average of the SNRs of the last 20 presentations, corresponding to 50 percent recognition of digit triplets. According to reference data by Smits et al. (2006) this continuous score can also be categorized as good (SRTn < -5.5 dB), insufficient ($-5.5 \leq$ SRTn ≤ -2.8 dB), or poor hearing ability (SRTn > -2.8 dB). The validity and reliability of the NHT have been proven to be good in several studies (Smits et al., 2004; 2006; Nachtegaal et al., 2009a).

After completion of the NHT at T0, participants were asked whether they had performed the test with (aided) or without hearing aids (unaided). The group of participants using hearing aid(s) were instructed to perform the hearing test at T1 twice (aided and unaided). Participants *without* hearing aid(s) or those who reported using a cochlear implant were asked to perform the test at T1 just once. In the current study, only unaided SRTn data was used (see next section Sample). This was to avoid any bias from differences in hearing aid amplification or hearing aid settings between T0 and T1.

Sample

The aim of the present study was to investigate the change in SRTn between T0 and T1. As the NL-SH study is a Web-based study with some variation in how participants performed the NHT at T0 and T1, strict selection criteria applied for inclusion to the present study. SRTn scores were included if: ① both tests were performed unaided, and ② both tests were performed using the same transducer (either headphones or loudspeakers were used at both T0 and T1). The following exclusion criteria were used:

- Using a cochlear implant when performing the NHT at T1. Unfortunately no information was available about how participants with a cochlear implant performed the NHT at T0 (with or without cochlear implant). Hence, any observed change in SRTn for these participants could have been attributed to various factors which we would not have been able to isolate and therefore, these twenty-six participants were excluded.
- SRTn scores with standardized residuals ≥3 between SRTn at T0 and SRTn at T1 were considered as outliers. In linear regression analyses with the SRTn at T1 as outcome and the SRTn T0 as determinant, the option of calculating standardized residuals (i.e., the standardized differences between the observed and predicted values) was used. Only three data points were categorized as an outlier.
- Having a SRTn score near the maximum score of the speech-in-noise test (between +3.0 and +4.0 dB SNR) at T0 or T1. The NHT cannot present stimuli with favorable SNRs (maximum is +4 dB SNR). Hence, the test is not sensitive for positive changes in SRTn for high SRTn values, because of a ceiling effect. Twenty-three data points were therefore excluded.

Questionnaire data

Age was partitioned into four age ranges: 18 to 39, 40 to 49, 50 to 59, and 60 to 69 years. Educational level was divided into three levels: low (elementary school not finished / graduated of elementary school, or attended high school, but no degree), mid (high school graduate or having an associate's degree), and high (having a bachelor's degree, master's degree, or doctoral degree). Income was measured by asking the participants to choose their gross monthly income category: low (<1050 Euro), mid (between 1050 and 2550 Euro), high (>2550 Euro) and, unknown (do not know, do not want to state). Living arrangement was measured by asking the participants whether they lived together with others or not. The response categories were: single, living alone; living with partner; living with partner and child(ren); living with parents together; living as a single parent with child(ren). Chronic conditions, such as diabetes, cardiovascular disease, asthma or Chronic Obstructive Pulmonary Disease (COPD), and rheumatoid arthritis were assessed with a list of 27 conditions (Mootz & van den Berg, 1989) as is used by Statistics Netherlands (see Stam et al., 2014). Participants were asked to check the box for a chronic condition or disease if it was present at that time, or during the last twelve months. The total number of chronic medical conditions was represented in five categories: none; one; two; three; or four or more chronic medication conditions. All above variables were collected at T0.

Statistical analyses

First, characteristics of those lost to follow-up were determined and the study samples at T0 and T1 were compared to investigate selective attrition. Means, standard deviations (SDs), and/or percentages were reported for parameters such as demographics and hearing status. Group differences were tested with independent sample t-tests for continuous variables, and Chi-square tests for dichotomous measures. Descriptive characteristics of the study sample at T0 were also reported. A paired t-test was used to test whether SRTn significantly differed between T1 and T0. Mean differences, 95% Confidence Intervals (95% CIs) and p-values were calculated.

The aim of the present study was to determine whether age, gender, educational level, initial level of speech recognition, and the number of chronic conditions were associated with a change in SRTn over a five-year period. Therefore, linear regression models were built with one outcome measure, and several variables as determinants (multivariable linear regression analyses). A backward selection procedure was applied to develop a regression model with only significant determinants of the change in SRTn over five years. Regression coefficients, 95% CIs, and p-values were reported. A p-value <0.05 was considered as statistically significant. Sensitivity analyses were performed to investigate the potential bias on the current results when the participants with SRTn scores in the ceiling range were included in the analyses. All statistical analyses were performed with SPSS, version 20.0.

RESULTS

Characteristics of the study sample

As described in Figure 1, 1434 participants were invited for T1. Of them, 930 (65%) partially or fully completed the questionnaire, and 819 (57%) participants also completed the NHT.

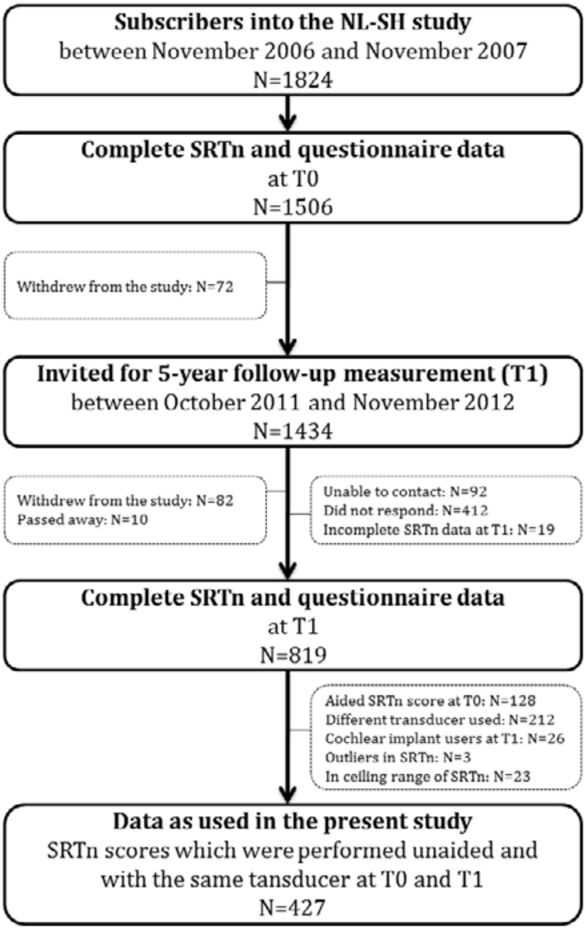

Figure 1: Flowchart of participants flow through the NL-SH study.

When comparing the response and nonresponse group at the T1 measurement, it was found that some subgroups were more often found to be lost to follow-up. Significant selective attrition was found for participants with better hearing ability, who were on average three years younger, had a lower educational level, and were more often a single parent with child(ren) at T0 than the responders. No selective attrition was found for gender, income, marital status, and the number of chronic health conditions.

Table 1 shows the characteristics of the study sample at T0 (N=427). More women than men participated and the mean age was 47 years. More than half of the study population reported a high level of education at T0. The proportion of participants with and without difficulties in speech recognition in noise were almost equal: 57 percent were categorized as having a 'good' speech recognition ability.

Change in speech recognition in noise

When calculating the change over time in audiological monitoring, it is important to account for regression towards the mean (McMillan et al., 2013). Due to the involvement of random measurement error and the independence of the measurements at T0 and T1, T0-SRTn values that are better than the population average will tend to increase (i.e., deteriorate) at T1, whereas T0-SRTn scores that are worse than population average of SRTn will decrease (i.e., improve) at T1. Thus, in addition to the raw shift in SRTn an additional change score was computed. The raw shift was calculated by: $\Delta SRTn = SRTn_{T1} - SRTn_{T0}$. The shift adjusted for regression towards the mean (Jones & Spiegelhalter, 2009) was calculated by: $\Delta SRTn_{adj} = SRTn_{T1} - (SRTn_{T0} * \rho + \mu * (1 - \rho))$. Where ρ is the population correlation between T0 and T1, and μ is the average $SRTn_{T0}$ of the study population. These values were included in the formula for $\Delta SRTn_{adj}$: ρ=0.64 and μ = -5.51 dB SNR.

The mean change in SRTn over five years for the total group, and for subgroups is shown in Table 2. For the total group of 427 participants between 18 and 70 years of age, a significant increase (i.e., deterioration) in SRTn of 0.38 dB SNR over five years was found (95% CI: 0.15 – 0.60; p=0.001). The deterioration in SRTn (calculated by both ΔSRTn and $\Delta SRTn_{adj}$) was greater in older age groups than in younger age groups. The age group of 50 to 59 years old at baseline had the largest deterioration in SRTn over five years ($\Delta SRTn_{adj}$: 0.77 dB SNR [SD: 2.53]).

Table 1: Baseline characteristics of the current study sample.

		N	Values at T0
Demographics			
Gender	Men (%)	163	38.2
	Women (%)	264	61.8
Age	Mean (SD), in years	427	47.1 (12.1)
	Range, in years	427	18 – 69
	18 – 39 years (%)	112	26.2
	40 – 49 years (%)	107	25.1
	50 – 59 years (%)	141	33.0
	60 – 69 years (%)	67	15.7
Educational level	Low (%)	63	14.8
	Mid (%)	119	27.9
	High (%)	245	57.4
Hearing and health status			
SRTn	Mean (SD), in dB SNR	427	-5.51 (2.69)
	Range, in dB SNR	427	-10.2 – 2.7
	Good hearing status (%)#	245	57.4
	Insufficient hearing status (%)#	117	27.4
	Poor hearing status (%)#	65	15.2
Number of chronic conditions	Mean (SD)	427	1.62 (1.64)
	Range	427	0 – 13
	None (%)	114	26.7
	One (%)	127	29.7
	Two (%)	89	20.8
	Three (%)	44	10.3
	Four or more (%)	53	12.4
Test conditions			
Type of transducer used	Headphone (%)	164	38.4
	Speaker (%)	263	61.6

SD: Standard deviation; SRTn: Speech-Reception-Threshold; db SNR: decibel Signal-to-Noise Ratio;
 # According to Smits et al (Smits et al, 2006b) scores on the National Hearing Test were categorized in three categories: good (SRTn > 5.5dB), insufficient (-5.5 ≤ SRTn ≤ 2.8 dB), and poor hearing ability (SRTn > -2.8 dB).

Figures 2 and 3 provide more insight into the relationship between age and speech recognition in noise. The scatter plot (Figure 2) shows that older NL-SH participants had on average poorer levels of speech recognition in noise (averaged SRTn over T0 and T1) compared with younger NL-SH participants. Figure 3 displays the SRTn scores at both measurement rounds, per age group. It shows that the largest deterioration in speech recognition ability was found in the age group of 50 to 59 years at baseline, as the vertical difference between the circle (T0) and triangle (T1) is largest for that age group.

Table 2: Descriptive information about the change in speech-recognition in noise (SRTn) over five years.

		$SRTn_{T0}$ dB SNR		$SRTn_{T1}$ dB SNR		$\Delta SRTn$ dB SNR		$\Delta SRTn_{adj}$ dB SNR	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Total group		-5.51	2.69	-5.13	2.89	0.38	2.37	0.38	2.22
Subgroups at T0									
Gender	Women	-5.30	2.51	-4.98	2.80	0.32	2.30	0.39	2.18
	Men	-5.85	2.93	-5.38	3.02	0.47	2.49	0.35	2.30
Age	18 – 39 years	-6.31	2.32	-6.08	2.36	0.23	1.98	-0.05	1.81
	40 – 49 years	-5.67	2.79	-5.40	2.89	0.27	2.10	0.21	2.00
	50 – 59 years	-4.95	2.76	-4.39	3.13	0.56	2.69	0.77	2.53
	60 – 69 years	-5.10	2.66	-4.71	2.68	0.39	2.68	0.54	2.36
Educational level	Low	-4.75	2.60	-4.20	2.68	0.55	2.42	0.82	2.19
	Mid	-5.63	2.86	-5.24	3.00	0.38	2.27	0.34	2.16
	High	-5.65	2.61	-5.32	2.84	0.33	2.42	0.28	2.25
Number of chronic conditions	None	-6.24	2.63	-5.63	2.75	0.61	2.14	0.35	2.02
	One	-5.36	2.64	-5.11	2.93	0.24	2.32	0.30	2.22
	Two	-5.56	2.85	-5.33	2.70	0.22	2.35	0.21	2.07
	Three	-5.07	2.17	-4.57	2.69	0.50	2.84	0.66	2.58
	Four or more	-4.60	2.77	-4.26	3.32	0.34	2.65	0.67	2.59
SRTn category	Good	-7.38	1.09	-6.54	1.88	0.84	1.91	0.17	1.83
	Insufficient	-4.32	0.79	-4.09	2.59	0.22	2.54	0.65	2.53
	Poor	-0.61	1.51	-1.72	2.89	-1.10	2.96	0.66	2.84

SD: Standard deviation; SRTn: Speech-Reception-Threshold; T0: Baseline measurement; T1: five- year follow-up; dB SNR: decibel signal-to-noise ratio

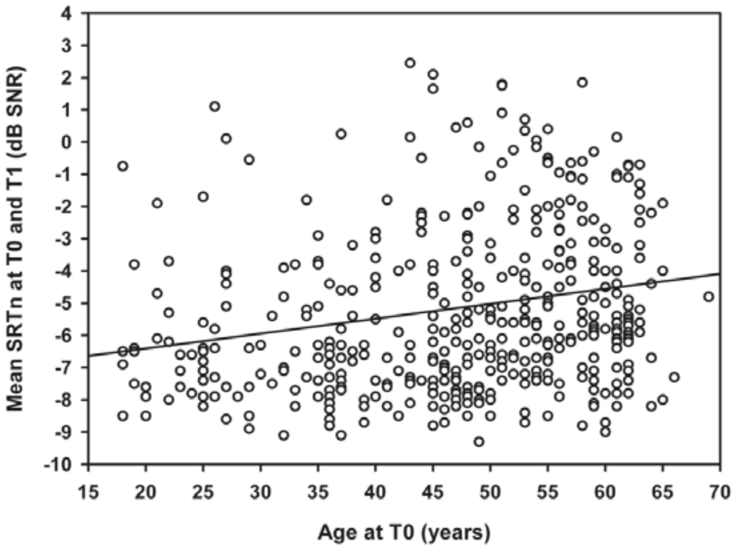

Figure 2: Speech recognition in noise (averaged Speech-Reception-Threshold in noise [SRTn] over T0 and T1) as a function of age: results of the NL-SH study. SNR indicates Signal-to-Noise Ratio.

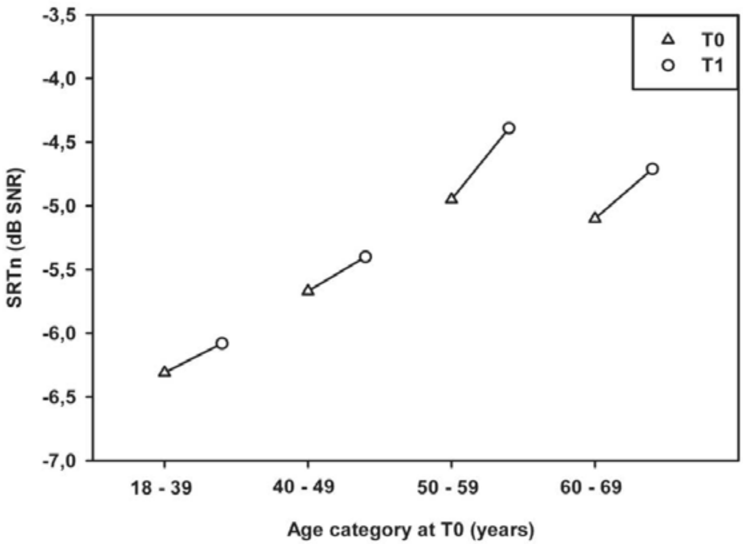

Figure 3: Change in speech recognition (SRTn) over five year time as displayed per age category. SNR indicates Signal-to-Noise Ratio.

Linear regression models were built to investigate whether age, gender, educational level, initial level of speech recognition, and the number of chronic conditions could be associated with a change in SRTn over a five-year period. Results from the full multivariable regression models with all factors included are shown in Table 3. Results are presented for both ΔSRTn and $\Delta SRTn_{adj}$. In the models, the age group of 50 to 59 years was the only subgroup which was significantly associated with a change in speech recognition over five years. Gender, educational level, and the number of chronic conditions appeared to be nonsignificant determinants of a change in SRTn. In the final model, including the factors age and baseline SRTn (data not shown), ΔSRTn for those aged 50 to 59 years was 0.64 dB SNR compared to the 18 to 39 years age group (95% CI: 0.07 – 1.22; p:0.028), adjusted for initial speech recognition level. In the final model with the adjusted change score as outcome, including only the factor age (data not shown), it was found that $\Delta SRTn_{adj}$ in the same age group was 0.82 dB SNR (95% CI: 0.27 – 1.37; p:0.004).

To investigate the potential bias of excluding respondents with SRTn values in the ceiling range, all regression models were rerun with all participants included. Thus, those with the poorest SRTn scores (i.e., between +3.0 and +4.0 dB SNR at T0 or T1) were now incorporated, resulting in a total of 450 participants. This sensitivity analyses yielded similar results. The mean ΔSRTn was 0.40 dB SNR (SD: 2.51) and this difference (i.e., deterioration) over five years was found to be statistically significant ($p<0.001$). Results from the multivariable linear regression analyses were similar again, with the age category of 50 to 59 years being the only significant subgroup associated with a deterioration in speech recognition over five years (ΔSRTn). The effect size of this age category was slightly higher than in the earlier reported effect analyses (beta: 0.73 dB SNR (95% CI: 0.18 – 1.33; p:0.018)). Neither the remaining age categories nor the subgroups for gender, educational level, and the number of chronic conditions were significantly associated with a deterioration in speech recognition over five years in these sensitivity analyses.

Table 3: Results of the linear regression analyses between subgroups and the change in SRTn over five years.

		Outcome: ΔSRTn Multivariable linear regression model			Outcome: $\Delta SRTn_{adj}$ Multivariable linear regression model		
	Subgroups at T0	**Beta dB SNR**	**95% CI dB SNR**	**p-value**	**Beta dB SNR**	**95% CI dB SNR**	**p-value**
Gender	Women	—	—	—	—	—	—
	Men	-0.05	-0.54 – 0.44	0.839	-0.12	-0.59 – 0.36	0.628
Age	18 – 39 years	—	—	—	—	—	—
	40 – 49 years	0.18	-0.44 – 0.79	0.575	0.20	-0.39 – 0.80	0.506
	50 – 59 years	0.65	0.04 – 1.26	**0.037**	0.75	0.16 – 1.34	**0.013**
	60 – 69 years	0.46	-0.30 – 1.22	0.232	0.51	-0.22 – 1.25	0.170
Educational level	Low	0.40	-0.26 – 1.06	0.231	0.31	-0.32 – 0.95	0.331
	Mid	0.18	-0.33 – 0.70	0.486	0.16	-0.34 – 0.66	0.525
	High	—	—	—	—	—	—
Number of chronic conditions	None	—	—	—	—	—	—
	One	-0.25	-0.84 – 0.34	0.403	-0.13	-0.70 – 0.44	0.646
	Two	-0.35	-1.00 – 0.30	0.286	-0.30	-0.93 – 0.32	0.342
	Three	0.02	-0.81 – 0.84	0.970	0.07	-0.73 – 0.87	0.869
	Four or more	-0.23	-1.00 – 0.55	0.563	0.03	-0.72 – 0.78	0.940
SRTn category	Good	2.09	1.45 – 2.73	**<0.001**	-0.31	-0.93 – 0.31	0.323
	Insufficient	1.35	0.64 – 2.05	**<0.001**	0.02	-0.67 – 0.70	0.964
	Poor	—	—	—	—	—	—

SRTn: Speech-Reception-Threshold; T0: Baseline measurement; T1: 5 year follow-up; dB SNR: decibel signal-to-noise ratio

—: Used as reference category in the regression analyses

DISCUSSION

The aim of the present study was to investigate the extent to which speech recognition in noise, as measured with the NHT, changes over a time period of five years in mainly younger- and middle-aged adults. Our key finding is that on average, functional hearing as measured with speech stimuli, deteriorates by 0.38 dB SNR per five years in the group of adults aged 18 to 70 years. We observed that the deterioration differed between the age groups. In particular adults aged 50 to 59 years at baseline showed a significantly larger deterioration over time compared with the youngest age group.

At first glance, this approximate 0.4 dB SNR deterioration in speech recognition over five years seems a small change. However, considering the steepness of the psychometric function of the NHT, which is approximately 20 percent per dB, a 0.4-dB change corresponds to approximately 8 percent loss in speech recognition in difficult listening situations. Thus, on average, adults mainly within the working age range are having increasing difficulties in speech recognition at less favorable SNRs over the years. It should be noted that a 5-dB shift in SRT corresponds to approximately 40 dB difference in pure-tone thresholds as measured with pure-tone audiometry ($PTA_{0.5,1,2,4}$) (Smits et al., 2004). Hence, this rather small numeric change represents a relevant and significant impact on an individual's ability to understand speech in everyday life.

Comparison with other studies

Caution is warranted when interpreting data from different speech-in-noise measurements (Smits & Festen, 2011), due to different sets of speech material, study population, equipment, languages used, and the target point chosen (e.g., 50 percent intelligibility). Nevertheless, our result showing that the deterioration of speech recognition accelerates around the age of 50 years, is in agreement with earlier cross-sectional findings. For instance, in a large sample of UK adults (Dawes et al., 2014), it was reported that the prevalence of hearing impairment based on speech recognition in noise increased in participants older than their mid-50s. This was also reported by Plomp and Mimpen (1979) and by Smits et al. (2006).

The LASA study is the only prospective study to date in which the NHT was measured prospectively and with an overlapping age range. When comparing the current findings to the change scores observed in the LASA study, it can be concluded that the results are in agreement. This agreement seems mainly the case for the magnitude of deterioration in speech recognition as found in the 50 to 59 years age group in each of the studies. To illustrate, in the current study the change in SRTn (ΔSRTn) was 0.56 dB SNR over five years; in the LASA-study (Pronk et al., 2013) the decline was: 0.13 dB SNR per annum in 57 to 75 years group, amounting to 0.65 dB SNR over five years.

Unexpectedly, we found a smaller decline for the 60 to 70 years age group than for the 50 to 59 years age group. This is not in agreement with LASA results, in which it was found that the deterioration in SRTn was comparable in the age groups of 57 to 65 years and 65 to 75 years. An explanation for this finding may be that the two study populations differed slightly, not only in terms of participant characteristics but also in the procedures used to collect data. In addition, participants over 60 years of age in the NL-SH study may be relatively healthier (physically and mentally) than the participants in the LASA study or the general population, because they are more highly educated than those in LASA. Also, LASA is a population based cohort study whereas the NL-SH uses a an open subscription approach and represents a convenience sample.

The results of the present study seem to indicate that deterioration in speech recognition over the life span is not necessarily linear. When combining the current findings with those of the LASA study (Pronk et al., 2013), there seems to be an acceleration in decline encompassing the age of 50 years and again around the age of 75 years. From studies measuring pure-tone thresholds prospectively, it is known that although both the incidence and progression of hearing loss increase with age (Cruickshanks et al., 2010; Mitchell et al., 2011), accelerations may occur. This was shown by Kiely (2012): the slope of the curve is generally steeper for adults aged 75 and 90 years at baseline than for adults aged 60 years at baseline. It must be noted that adults older than 70 years are not included in the NL-SH and hence, it was not possible to investigate whether the speech recognition further deteriorated at older ages.

Although the magnitude of change in speech recognition differed for subgroups (gender, other age categories, educational level, and chronic conditions), the differences between categories (e.g., men versus women) were not found to be statistically significant in the current analyses. It may be that within age categories, differences between subgroups may be important. For instance, it may be that gender was a predictor of deterioration in the age group of 50 to 59 years, because of menopause in women (Hederstierna et al., 2010). Due to relatively small sample sizes per age group, regression models including many predictor variables per age group could not be performed. This issue needs further investigation.

To our knowledge, this is the first study investigating levels of education, and the number of chronic conditions in relation to changes in speech recognition over time. Cross-sectional studies found associations between lower socioeconomic background and hearing ability in noise (Stam et al., 2013; Dawes et al., 2014), but in the current analyses, a difference in SRTn decline over time was not found for adults with differing levels of education.

Gender was not associated with deterioration in SRTn in the present study. Thus, the current results obtained for young- and middle-aged adults mainly expand further on the evidence that gender seems to play no role in the amount of change in speech recognition in noise over time (Dubno et al., 2008; Pronk et al., 2013). Previous cross-sectional studies using speech recognition in noise measures observed that older men had significantly poorer SRT scores than older women (Smits et al., 2006, Pronk et al., 2013, Dawes et al., 2014). However, in younger age groups this gender difference was not observed (Dawes et al., 2014). The suggestion of Kiely et al. (2012) that males may have an onset of pure-tone hearing loss at an earlier age than females, may also apply to speech recognition in noise measures. There may be a gender difference in the absolute SRTn thresholds at a certain moment of time (cross-sectionally), but that doesn't mean that the *change* in hearing over time is also different for men and women.

As suggested by Kiely and colleagues (2012), it might be that poorer cardiovascular health and an unhealthy lifestyle could cause pure-tone hearing loss to occur at an earlier age, without affecting the rate of decline per se in older adults. However, the association between the number of chronic conditions reported at T0 and the change in SRTn was not significant in the current study. A possible explanation for this finding is that a sum score of 27 chronic conditions present (yes/no) was used, which made it difficult to identify the specific influence of one specific chronic condition. In addition, the sample sizes of groups with one chronic condition (e.g., diabetes, cardiovascular disease) was too small to test their specific influence on the rate of decline. For instance, fewer than ten participants reported cardiovascular disease (stroke or heart infarct) at

T0. This issue of comorbidity in relation to decline in speech recognition needs further investigation in future prospective cohort studies.

It might be that other factors, such as cognition, influence the longitudinal deterioration of speech recognition. Studies have shown associations between pure-tone audiometry and a broad range of cognitive functions, such as orientation, concentration, concept psychomotor speed, and executive function in older adults (Valentijn et al., 2005; Kiely et al., 2012; Lin et al., 2013). A relationship has been reported between deteriorating speech recognition over time and slower information processing speed (Pronk et al., 2013). It is also suggested that an accelerated decline of central auditory processing is associated with speech recognition (Divenyi et al., 2005). It is likely that changes in cognitive factors, such as short term working memory and attention, played a role in the decline in speech recognition in our study. A cognitive test is not yet part of the NL-SH test battery. Therefore, we could not examine its association with speech recognition in noise and consequently this needs further investigation.

Finally, we investigated the hypothesis that participants with poorer hearing ability at the start of the study had larger deterioration in speech recognition over time. When including the raw shift in speech recognition over time as outcome (ΔSRTn), and including the baseline speech recognition scores, one would conclude that in those with poorer speech recognition, scores would improve over time. However, regression towards the mean was likely to explain this results. That the association between the baseline speech recognition score and the adjusted shift ($\Delta SRTn_{adj}$) was not statistically significant, confirms this finding. Thus, based on results of the current study when taking regression towards the mean into account, the level of baseline speech recognition ability seems not to be associated with a change in speech recognition ability over time.

The current findings add to the literature about how to analyze changes in speech recognition over time. The results also provide input for future studies. It underlines the importance of calculating adjusted change scores (McMillan et al., 2013) when investigating changes in hearing ability over time. For instance, age and SRTn at baseline are related, with older participants having poorer speech recognition scores. By only calculating the raw shift in SRTn over time, without examining the change scores adjusted for regression towards the mean, one would not be able to tell the two apart. In other words, one would not be able to know the extent to which the regression towards the mean phenomenon would have biased the results. It is important to note that the adjusted change scores per subgroup (e.g., per age category) should be interpreted with some caution, because values (correlation coefficient and mean baseline SRTn) of the full sample were included in the formula. The adjusted change scores within subgroups (e.g., age categories of Tables 2 and 3) might be biased estimates due to the sample size imbalance between subgroups. Additional analyses showed that the age-specific adjusted SRTn scores and the absolute change scores in SRTn yielded comparable results. This supports the finding that adults aged 50 to 59 years had the largest deterioration in speech recognition in noise over time. Future prospective studies with a longer time frame are needed to further expand the evidence of the deterioration in speech recognition over a lifetime. Studies investigating the incidence (newly reported problems with speech recognition in noise) and progression of speech recognition difficulties in noise are needed to determine whether initial speech recognition score is a determinant of change in speech recognition over time.

Possible limitations

The measurement error in the speech-in-noise test usually increases with poorer SRTs (Smits & Festen, 2011). For the NHT the measurement error was found to be approximately 1 dB (Smits & Houtgast, 2005). This relatively large measurement error compromises the sensitivity of the test to small changes, and might explain why no significant differences between categories of determinants (e.g., men versus women) were found.

Due to the strict inclusion criteria, not all available SRTn data from the two NL-SH measurement rounds could be analyzed in the present study. This might have influenced the statistical power. However, as test environments in Web-based studies are less controlled than in a laboratory setting, we concluded that it is important to use such strict criteria. Moreover, by using strict criteria we were able to compare our results with other studies such as the LASA study. The sensitivity analyses showed that our key findings are robust against a different selection criterion (including participants with SRTn scores in the ceiling range or not). In both analyses, the average change in speech recognition was comparable: 0.38 versus 0.40 dB SNR, respectively.

More women than men participated in the NL-SH, and the educational level of the NL-SH participants is superior than that of the general population (Stam et al., 2014). Also, in the current study some selective drop-outs at follow-up were observed. Younger participants, those with better hearing ability, a lower education level, and those being a single parent were more likely to drop out. This selective loss to follow-up may have diluted the effects.

Conclusions

Our findings indicate that changes in speech recognition over a five-year period do not only exist in old age (>70 years), but also in younger-aged adults. The average deterioration in SRTn was approximately 0.4 dB SNR over five years. This rather small numeric change in speech recognition represents a relevant impact on an individual's ability to understand speech in everyday life. An accelerated decline was observed in the 50 to 59 years age group, indicating a nonlinear change in speech recognition over the life span. Gender, educational level, and the number of chronic conditions were not found to be associated with a change in speech recognition over time. Future prospective studies covering the lifespan of adults and taking a multifactorial approach are recommended to investigate the mechanism underlying the differential effect of age on changes in speech recognition in noise.

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